International Symposium on Niobium Microalloyed Sheet Steel for Automotive Application
Edited by S. Hashimoto, S. Jansto, H. Mohrbacher, and F. Siciliano
TMS (The Minerals, Metals & Materials Society), 2006

PROCESSING OF MICROALLOYED STEEL FOR AUTOMOTIVE APPLICATIONS ON A THIN SLAB PLANT

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Abstract

The use of thin slab casting and direct rolling is well suited for the production of hot and cold rolled strip from niobium microalloyed low-carbon high strength steel grades. Thermomechanical processing by controlling hot work hardening and softening processes of austenite and its polymorphic transformation into ferrite results in a powerful microstructure refinement. This is a sound basis for producing high strength hot strip, combined with excellent ductility and toughness. Hot strip from thin slab plants can easily be further processed to cold rolled and surface treated cold rolled strip. However, special care has to be taken to meet particular surface quality requirements for automotive applications.

Introduction

From the very first beginnings in the 1990s, thin slab casting technology has been developed to a standard technology for hot strip production. Figure 1 shows the actual locations of thin slab plants all around the world. The highest concentration of such plants is found in the US, in China but also in Europe. A recent project has been presented by SeverCorr LLC building up a thin slab plant in Columbus (Mississippi, US) for the production of exposed automotive sheet. Products will include hot-rolled, cold-rolled and coated steel.

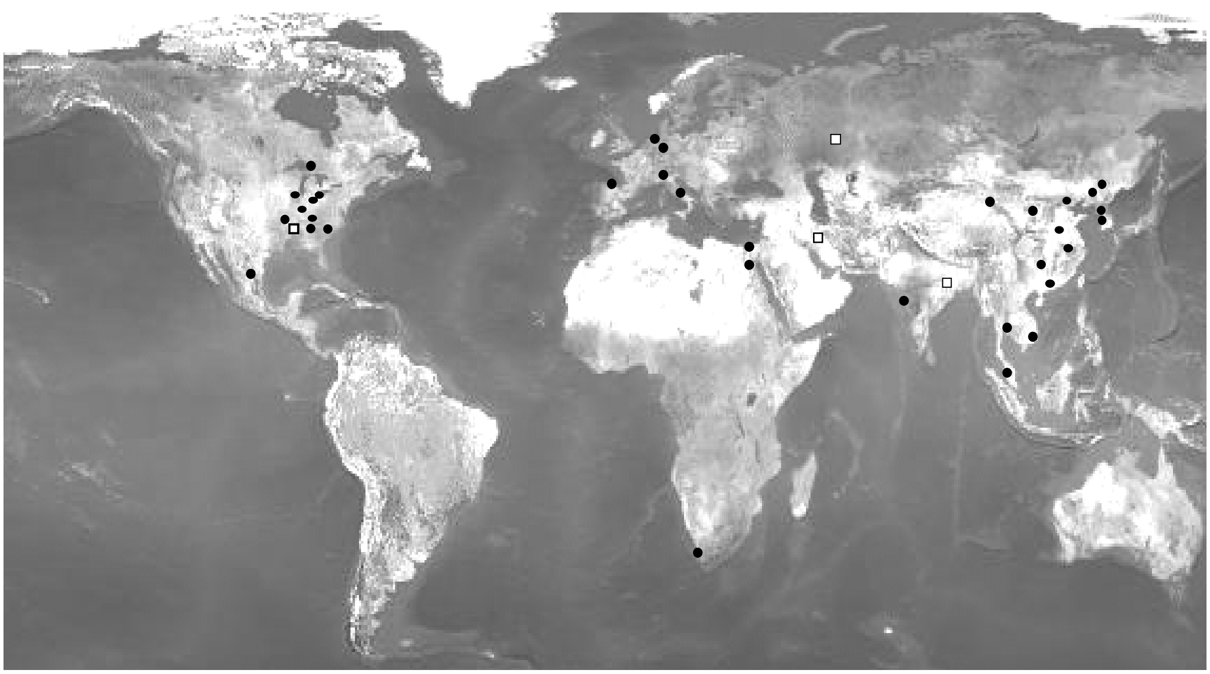


Figure 1. Worldwide locations of thin slab casters (full symbols: operative plants, open symbols: planned projects).

The use of thin slab casting followed by direct rolling is well placed for the production of low-carbon niobium microalloyed steels. In this process thin slabs of thickness between 52 and 90 mm are cast and directly hot rolled to hot strip with gages between 1 and 12 mm. Figure 2 schematically represents a typical plant layout.

On plant start up after commissioning, a basic product range comprising non-microalloyed steel grades for use as general structural steel and mild unalloyed steel for cold rolling is often produced (see Table I). After a short run-up phase thin slab producers often turn to the production of higher value-added steel grades [1,2].

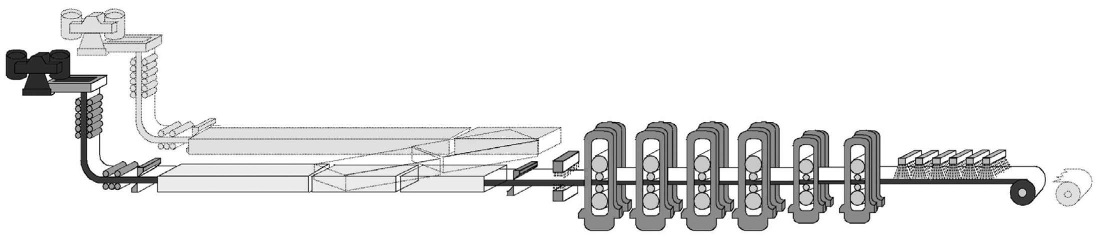


Figure 2. Basic layout of a thin slab casting plant with direct hot rolling.

Due to technical and economic reasons the automotive industry requires better weldability and reduced weight by using higher strength steels enabling improved weight/strength ratio, better toughness as well as better cold formability. Surface quality is an important aspect especially for the automotive industry. The following report describes the processing of Nb-microalloyed steel by thin slab casting and direct rolling with special regard to automotive applications.

Table I. Typical basic product range (DIN EN 10111 and DIN EN 10025).

Steel grade		**C_{max}**	**Mn_{max}**	**YS [MPa]**	**UTS [MPa]**	**El_{min} [%]**
Mild unalloyed steel for cold rolling	DD11	0.12	0.60	170-340	≤ 440	28
	DD12	0.10	0.42	170-320	≤ 420	30
	DD13	0.08	0.35	170-310	≤ 400	33
General structural steel	S185	-	-	185	290-510	18
	S235	0.17	1.40	235	360-510	26
	S275	0.18	1.50	275	430-580	22
	E295	-	-	295	490-660	20
	S355	0.20	1.60	355	510-680	21

Metallurgical aspects of microalloyed steel production

The metallurgy of direct hot rolling in combination with thin slab casting differs significantly from conventional production. As can be seen from the temperature cycle in Figure 3, the solidified strand should not cool below around 1000°C before hot rolling. Consequently, the austenite grain size is larger owing to the lower total deformation and to the lacking grain refinement induced by the successive $\gamma \rightarrow \alpha \rightarrow \gamma$ phase transition in the conventional rolling process involving slab reheating.

Lowering the carbon content will improve toughness, decrease the transition temperature and enhance surface quality and welding behavior. Low carbon content also has a positive influence on segregation behavior [3]. Low nitrogen content positively affects ageing stability and toughness in the heat-affected zone of the weld seam, as well as resistance to intercrystalline stress-corrosion cracking.

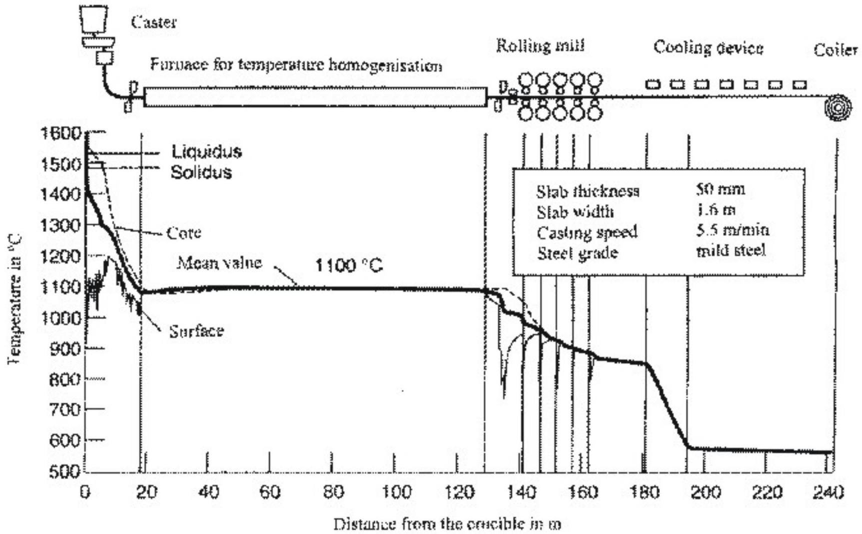


Figure 3. Typical temperatures in a CSP thin slab casting device.

Thin slab casting and direct rolling makes use of austenitization via a $\delta \rightarrow \gamma$ - polymorphic transformation. In this case the austenitization temperature is high and the initial austenitic grain comparatively coarse. Microalloying with Niobium and thermomechanical processing are excellent tools for the powerful subsequent microstructure refinement.

The typical impact of different microalloying elements on strength and toughness properties is highlighted in Figure 4. Grain refinement is the only mechanism that simultaneously increases strength, toughness and ductility, making niobium the most effective element, even if added in small quantities as is indicated in Figure 4.

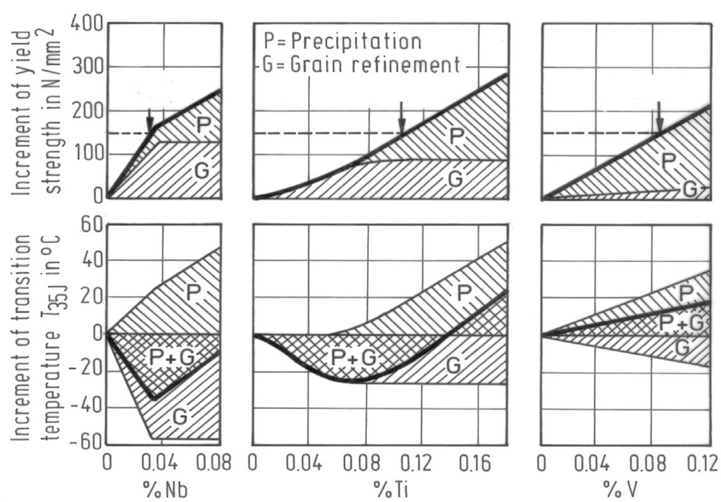


Figure 4. The contribution of microalloying elements to ductility and strength of 0.08% C, 0.90% Mn steel.

The grain refining effect of niobium is mainly due to delaying or preventing recrystallization in the last stands of the rolling mill. Pan caked grains as well as a high dislocation density of the austenite enhance ferrite nucleation. By lowering the austenite to ferrite transformation temperature (A_{r3}) niobium simultaneously enhances the ferrite nucleation rate and reduces the grain growth rate. The combined effects lead to a particularly fine-grained transformation microstructure. Niobium also contributes to precipitation hardening. In order to make optimum use of its metallurgical potential niobium has to remain in solid solution while the slab moves through both the casting machine and the tunnel furnace.

Figure 5 relates the precipitated fraction of initial niobium content to the available nitrogen content after holding at various temperatures [acc. to 4, 5, 6]. The figure shows that niobium precipitation is completely suppressed above around 1050°C by lowering the nitrogen content to about 53 ppm, even when thermal equilibrium is reached. Thus niobium stays in solid solution, promoting grain refinement during thermomechanical rolling. For this same reason, it is necessary to avoid any supercooling of the strand below this temperature, including edges of the thin slab, in the secondary cooling section of the casting machine before entering the soaking furnace [7].

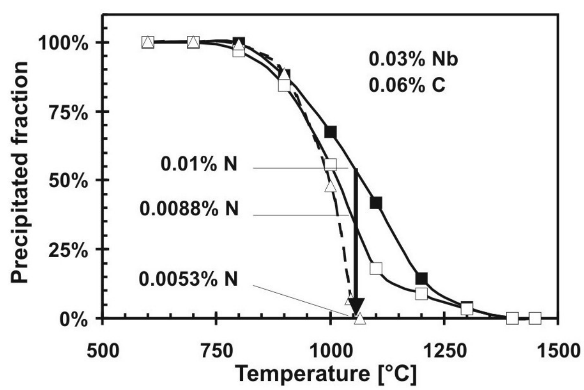


Figure 5. Influence of nitrogen on the precipitated fraction of initial niobium content.

Titanium-nitride (TiN) precipitation already starts during solidification of the slab and is completed when leaving the tunnel furnace. Although TiN precipitates forming during the tunnel furnace passage are most finely dispersed, they have no austenite grain refining effect [8]. The use of titanium is often avoided because it may enhance premature niobium precipitation by forming of mixed titanium-niobium-nitrides. The formation of star-like precipitates having TiN-core and arms of Nb(C,N) is described by DeArdo et al. in [9]. Furthermore, titanium is supposed to cause nozzle clogging. When compared to Ti-microalloyed steel, Nb-microalloying offers a considerable reduced scattering of the mechanical properties of the hot strip [10].

After deoxidation, FeNb is added gradually in batches to the ladle, while soft bubbling with argon gas enhances the homogenization and cleanliness of the melt. This way, maximum recovery of niobium is achieved. Care has to be taken that the slag does not trap FeNb lumps. An important preparatory stage for thin-slab casting is calcium treatment to improve the castability of the melt, prevent nozzle clogging and to raise toughness by inclusion control. The best mechanical properties are attained when the soaking furnace is operated at temperatures at or above 1100 °C, with the residence time in the furnace being about 20 minutes. This enables hot rolling to start at a temperature that is high enough to ensure complete recrystallization in the first stand of the hot rolling mill.

Direct rolling typically starts with the entry of the as-cast thin slab into the first stand of the finishing mill without any previous roughing pass. To obtain optimum strength and toughness properties, hot rolling has to compact the dendritic as-cast microstructure and to achieve a fine-grained microstructure. This affords a two-stage rolling strategy with start rolling above the recrystallization stop temperature and finish rolling in the non-recrystallizing temperature range.

Temperature and deformation in the first stand should be as high as possible in order to delete the initial as-cast microstructure by complete recrystallization [11, 12]. Therefore rolling should start at 1060 – 1080°C and the reduction ratio in the first stand should be ≥50 %.

It has been suggested that softening can be accelerated by dynamic recrystallization [7, 13, 14]. Figure 6 shows that for an initial grain size of 1000 µm, the critical strain for the onset of dynamic recrystallization is about 55% at 1080°C. Metadynamic recrystallization takes place without any incubation period immediately after dynamic recrystallization and is completed before entering in the next stand [7].

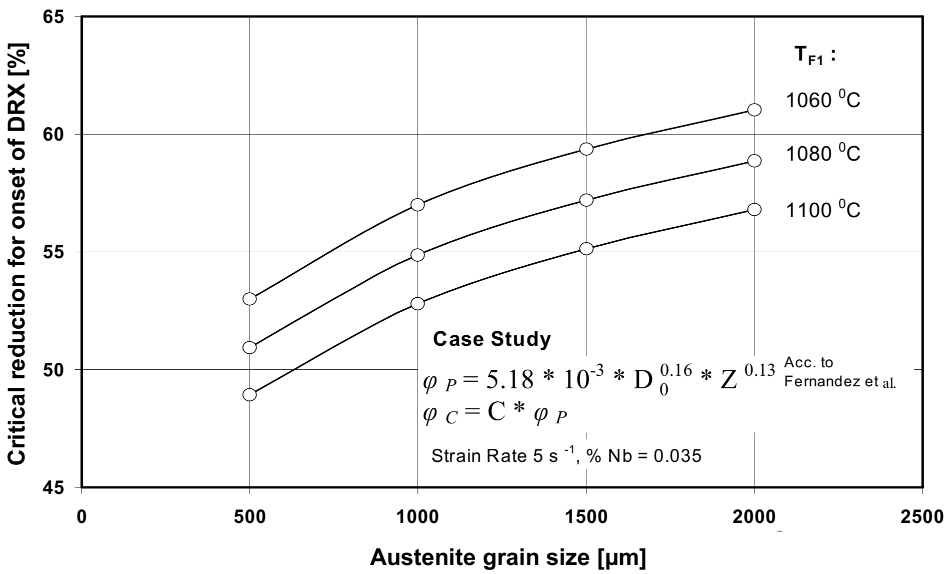


Figure 6. Effect of temperature and grain size on the critical reduction for the onset of dynamic recrystallization (DRX) [7 acc. to 13]

Finish rolling is completed below the austenite non-recrystallization temperature where the austenite grains remain flattened. There is a close correlation between the ferrite grain size that forms, the strain accumulated in the rolling mill, the austenite grain size and the cooling rate on the run out table that can be used for microstructural modeling as demonstrated in Figure 7 [7 acc. to 15]. For example: from a residual deformation of 0.8, an austenite grain size of 20 µm and an average cooling rate of 25°C/s, a ferrite grain size of approx. 5 µm is calculated. This corresponds well to the results obtained from experiments. Maximum grain refinement is achieved by applying early fast-cooling mode in the laminar cooling section [16].

The described solid-state reactions, and thus the final ferrite grain size, are closely linked to the macroscopic deformation of the slab during hot rolling. Research work mainly focused on skelp for line-pipe application. However, these results also apply to any HSLA hot strip for automotive use even when the final strip gage is typically lower in such applications. Figure 8 illustrates the relationship between toughness, given in terms of the ductile to brittle fracture transition temperature (FATT) and the total thickness reduction during hot rolling of microalloyed steel. It can be seen from this diagram that in the case of the X70 grade steel a transition temperature of -50°C can only be achieved when the slab thickness is ≥70 mm for a 10 mm thick hot strip.

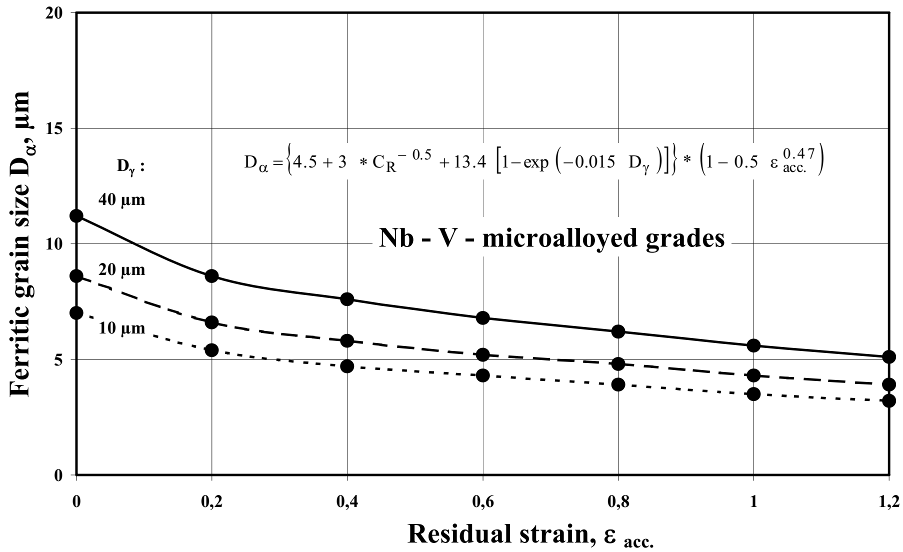


Figure 7. Grain refinement due to austenite to ferrite transformation [7 acc. to 15].

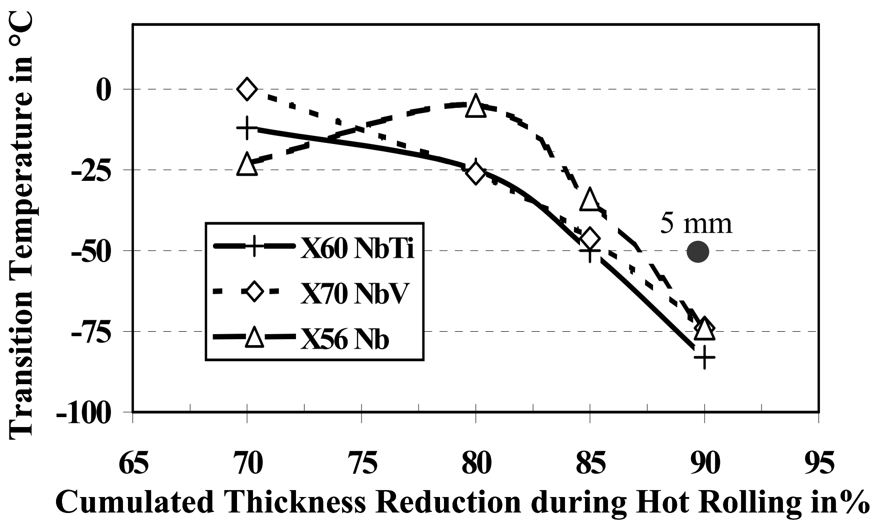


Figure 8. Total deformation and transition temperature in microalloyed steel.

The effect of the finish rolling temperature on the yield and tensile strength of the 10 mm strip is given in Figure 9. Lowering the finishing temperature to approximately 880°C results in an increase of both yield and tensile strength because of the greater work hardening of the austenite and the more intensive microstructure refinement during austenite to ferrite transformation.

To obtain stable process results and further improved toughness by grain growth-prevention in the lower austenite region, the finish rolling temperature may even be below 870°C. Further strengthening potential is still available as can be seen from Figure 9 [17].

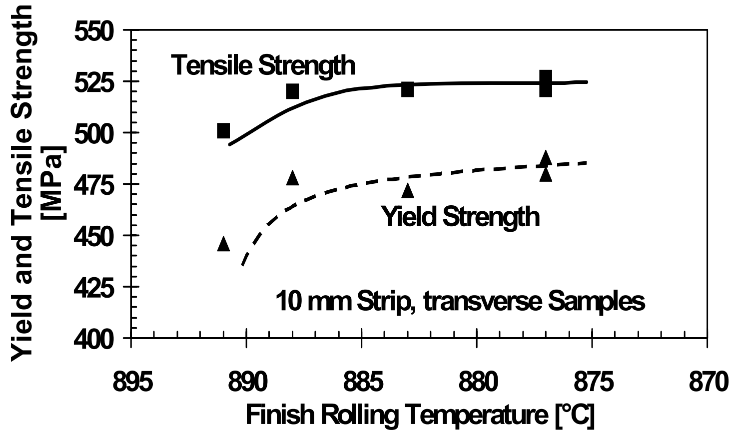


Figure 9. Influence of finish rolling temperature on strength properties of 10 mm X52 strip.

Table II summarizes the mechanical properties of 6 and 10 mm thick X52 hot strip [17]. Due to the pronounced texture after thermomechanical rolling, transverse samples show slightly higher strength compared to longitudinal samples. Strength and elongation of the 6 mm strip is higher than the 10 mm ones due to the greater amount of deformation and hence finer microstructure.

Table II. Mechanical properties of X52 hot strip.

	Gauge [mm]	YS [MPa]	UTS [MPa]	El (A_5) [%]	YS ratio [%]
Trial	6	488	544	26.0	0.9
		510	552	25.8	0.92
Trial	10	446	501	25.2	0.89
API X52 / X60 / X65		*≥ 359 / 414 / 448*	*≥ 455 / 517 / 531*	*≥ 20 / 18 / 18*	-

The excellent toughness properties are further underlined by the notch-bar impact results. Figure 10 shows that for both, longitudinal and transverse samples the upper shelf level is about 170 to 180 J [17]. The transition temperature is around -50°C and even at -100°C impact energy is still 60–80 J.

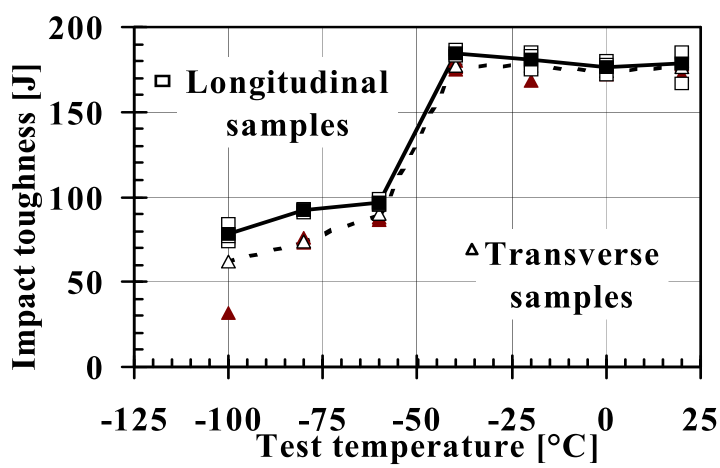


Figure 10. Toughness of X52 [5x10mm^2 Charpy V-notch].

Examples for automotive application

Figure 11 highlights the correlation between strength and ductile properties in terms of yield strength and total elongation of hot rolled strip from several HSLA-steel grades that have been produced by CSP thin slab technique [11]. They show similar characteristic as conventionally elaborated strip. The corresponding chemical compositions are given in Table III. Other examples for Nb-microalloyed HSLA-steels produced on a thin slab line are given by Corus in this book [18].

Table III. Chemical composition of CSP hot rolled strip HSLA-steel grades.

Grade	C	Mn	Si	P	S	Al_{total}	Nb	V	N	Ca
S315MC		0.3-0.5								
S355MC		0.7-0.9								
S420MC	≤ 0.066	1.0-1.2	≤ 0.6	≤ 0.01	≤ 0.01	0.02-0.035	0.02-0.06	≤ 0.15	0.004-0.020	0.002-0.004
S500MC		1.2-1.4								
S550MC S600MC		1.4-1.6								

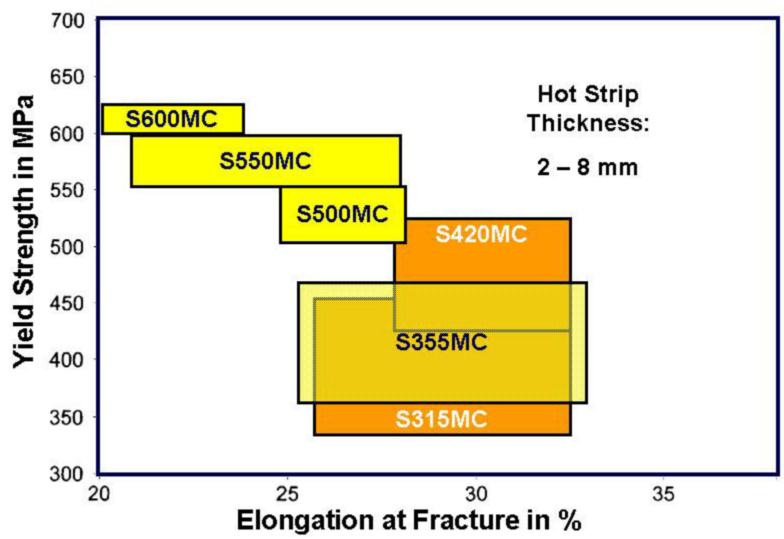


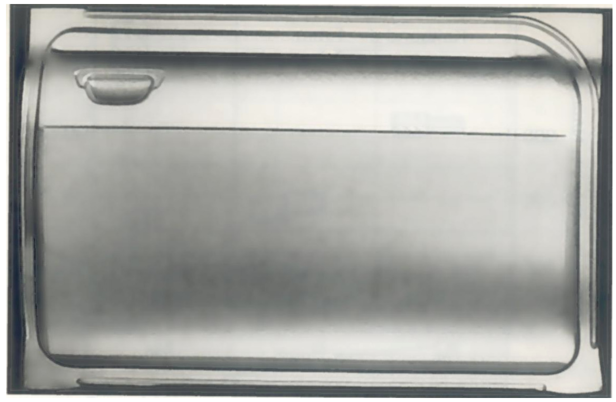
Figure 11. Mechanical properties of hot strip produced by thin slab casting.

Chemical Compositions of HSLA Steel Grades from CSP Plant

ThyssenKrupp Steel recently published results on the production of hot-rolled strip from HSLA and multiphase steel grades on their Casting Rolling Line [19]. Different microalloying concepts deriving from experience with conventional hot-strip production have been applied. Among the steel grades figured S355MC with V, S355MC with Nb and S420MC with Nb. A 1200 mm wide strip having a gage of 2.2 mm was reached when starting from 63 mm thin slab. The mechanical properties showed good homogeneity across the strip width and were inside the scatter band of conventionally produced hot strip. There was a tendency towards a finer microstructure in the Nb-alloyed grades.

Figure 12 gives two examples for automotive applications that have been produced by thin slab casting and direct rolling. The suspension part was produced from hot-rolled strip whereas the exposed part was made from cold-rolled strip. In addition, thin slab casting technology offers the possibility to produce thin hot strip having <1mm thickness. This way more expensive cold rolled strip may be substituted in non-exposed parts [2].

HSLA hot strip: Ford Pick-up rear axle support.



Cold rolled strip (St14): BMW outer door panel.

Figure 12. Examples for automotive parts from thin slab cast and direct rolled strip [2].

Summary and outlook

The concept of low-carbon, Nb-microalloyed steel is well suited for the production hot- and cold-rolled strip for automotive use on a thin slab and direct rolling plant. The slabs may have adequate surface quality upon careful processing during steelmaking and casting. Thin slab casting and direct rolling result in most homogeneous material properties over the strip length and width. Microalloying with niobium is an economic and effective means to produce high strength steel having excellent ductility and toughness via a fine-grained microstructure. The best results are obtained after a high total rolling reduction, low finish rolling temperature and fast laminar cooling.

It has been demonstrated by laboratory trials and industrial production that also multiphase steel such as TRIP, DP and CP can be produced by thin slab casting and direct rolling [2, 19]. These results show that all steel grades currently used in automotive applications can be produced by this technology. Future work will have to focus on surface quality for exposed panels.

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